Review

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Spectroscopic Data of W I, Mo I and Cr I Spectral Lines: Selection and Analysis

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Abstract. Plasma of electric arc discharges between composite Cu–W, Cu–Mo and Cu–Cr electrodes in argon flow and their spectra were studied by optical emission spectroscopy. Since values of oscillator strengths for W I, Mo I and Cr I presented in various sources are significantly different, selection of spectroscopic data for these elements (particularly oscillator strength) was expected to be useful for plasma diagnostics. The Boltzmann plot method was used as a tool for the selection of appropriate spectral lines and their spectroscopic data. The main result of the paper is W I, Mo I and Cr I spectral lines and spectroscopic data recommended for diagnostics of plasma with such metal impurities.

Key words. Plasma—emission spectrum—optical emission spectroscopy—spectral lines—tungsten—molybdenum—chrome.

1. Introduction

Composite materials on a base of copper with addition of refractory metals are widely used as electrodes or contact materials in electric industry applications (e.g. relays, commutators, circuit breakers etc.). Plasma emission spectrum of electric arc discharge between such materials contains spectral lines of Cu (which are well studied) and refractory metals (W, Mo and Cr). So such plasma can be used as spectroscopic tool for analysis and selection of W I, Mo I and Cr I spectral lines and their spectroscopic data.

In order to apply diagnostic techniques of optical emission spectroscopy, first, it is required to select 'convenient' spectral lines for plasma analysis, which must meet the following criteria: these lines are supposed to be isolated in the emission spectrum and to be intensive enough for their guaranteed registration. Moreover, the difference between excitation energies of their upper levels must be as large as possible, since it allows determining the temperature with minimal error.

Table 1. List of Cu I spectral lines and corresponding spectroscopic data recommended for diagnostics of plasma with addition of copper vapours (Boretskij 2011).

λ (nm)	g_k	g_i	E_k (eV)	E_i (eV)	$g_k f_{jk}$
427.5	6	8	4.84	7.74	0.9097
465.1	10	8	5.07	7.74	1.4218
510.5	6	4	1.39	3.82	0.0197
515.3	2	4	3.79	6.19	1.6466
521.8	4	6	3.82	6.19	1.9717
570.0	4	4	1.64	3.82	0.0057
578.2	4	2	1.64	3.79	0.0130
793.3	2	2	3.79	5.35	0.4246
809.3	4	2	3.82	5.35	0.6120

Spectroscopic data selection for atomic spectral lines among all existing literature sources presents the separate issue of plasma diagnostics. Critical analysis of up-to-date works on determination of spectroscopic data of copper atomic lines were performed by Babich *et al.* (2010) and Boretskij (2011), which allowed to carry out their selection. Table 1 presents Cu I spectral lines and their spectroscopic data that were selected and recommended for diagnostics of plasma with addition of copper.

Values of oscillator strengths for W I, Mo I and Cr I from various sources (see Tables 2, 3, 4) are significantly different, so it is reasonable to carry out their selection carefully. Quinet *et al.* (2011) have carried out calculation of transition probabilities for tungsten spectral lines, but results presented in this paper deal only with ultraviolet region of the spectrum.

As it was mentioned earlier, the emission spectrum of copper is well studied, so one can use plasma of arc discharge between composite copper electrodes to carry out the selection of spectral lines and the corresponding spectroscopic data of other elements, which are present in plasma. Boltzmann plot method was considered as a tool for the selection of W I, Mo I and Cr I spectral lines and their spectroscopic data. When plasma is in local thermodynamic equilibrium (LTE), then the slopes of Boltzmann plot lines corresponding to each spectroscopic plasma component must be the same. This slope depends on the excitation temperature of thermal plasma. In the same way, values of oscillator strength for W I, Mo I and Cr I spectral lines,

Table 2. Products of oscillator strengths f_{ki} by statistical weights of lower layer g_k of molybdenum spectral lines.

	$g_k f_{ki}$							
λ (nm)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
441.169	4.5	–	0.8433	–	0.8407		0.8441	1.5118
473.144	2.8	1.6596	1.6596	–	1.6613	1.5505	1.6576	2.2594
476.016	3.2	2.0654	2.0606	–	2.0756	2.0314	2.0623	2.9677
550.649	0.9	1.1481	1.1481	1.1142	1.0883	–	1.1487	1.241
553.303	0.59	0.8551	0.8531	0.7889	0.8238	–	0.8537	0.9179
557.044	0.27	0.4613	0.4602	0.3864	0.4508	–	0.4605	0.4801
603.066	0.2	–	0.2999	–	0.3587	–	–	–

[1] Corliss & Bozman (1962), [2] Ralchenko *et al.* (2010), [3] Kurucz & Bell (1995), [4] Schnehage *et al.* (1983), [5] Whaling *et al.* (1984), [6] Whaling *et al.* (1986), [7] Whaling & Brault (1988), [8] Palmeri & Wyart (1998)

Table 3. Products of oscillator strengths f_{ki} by statistical weights of lower layer g_k of tungsten spectral lines.

	$g_k f_{ki}$						
λ (nm)	Ralchenko *et al.* (2010)	Kurucz & Bell (1995)	Kirsanova (1969)	Obbarius & Kock (1982)	Den-Hartog *et al.* (1987)	Thevenin (1989)	Kling & Kock (1999)
429.46	0.184	0.170	–	0.1840	0.171	–	0.170
430.21	0.068	0.069	–	0.0677	0.069	–	–
468.05	0.031	0.032	–	0.0312	0.032	–	–
475.75	0.004	0.005	–	0.0037	0.005	–	–
484.38	0.029	0.034	0.025	0.0282	0.034	0.102	–
488.69	0.032	0.032	0.000	0.0313	0.032	–	–
498.26	0.003	0.005	0.002	–	0.005	–	–
500.615	0.030	0.031	0.026	0.0295	0.031	–	–
501.531	0.014	0.018	0.034	0.0138	0.018	–	–
505.33	0.026	0.022	0.013	0.0265	0.022	0.263	–
522.466	0.020	0.025	–	0.0198	0.025	–	–
551.47	0.016	0.010	–	0.0158	0.010	0.087	–

Table 4. Products of oscillator strengths f_{ki} by statistical weights of lower layer g_k of chrome spectral lines.

	$g_k f_{ki}$				
λ (nm)	Ralchenko *et al.* (2010)	Kurucz & Bell (1995)	Younger *et al.* (1978)	Sobeck *et al.* (2007)	Wujec (1981)
435.177	0.378	0.363	0.363	0.331	0.406
458.006	0.0225	0.0224	0.0316	0.021	0.038
464.617	0.198	0.199	0.199	0.181	0.193
487.080	1.12	1.122	1.122	0.977	–
532.834	2.88	2.884	2.818	–	–
540.979	0.189	0.190	0.190	0.214	–

which are in correspondence with the slope determined by intensities of Cu I spectral lines in Boltzmann plot, can be chosen.

It should be noted that spectroscopic investigations of electric arc discharge plasma, which contains vapours of more than one chemical element, require accurate selection of spectral lines for diagnostics. Particularly, Mo I, W I and Cr I spectra contain a large number of closely-spaced spectral lines with commeasurable intensities. In case of spectral device with low resolution capability, such lines can be registered as a non-separated line.

Such problem can be solved by accurate account of each component's contribution into the total intensity of non-separated spectral line, or by application of device with high spectral resolution for investigation of spectral lines' profiles, for instance, device for preliminary monochromatization with cross dispersion.

2. Selection of spectroscopic data for W I, Mo I and Cr I spectral lines

2.1 *Spectroscopic data of Mo I atomic lines*

For selection of Mo I spectral lines and corresponding spectroscopic data, plasma of electric arc discharge of 3.5 A current in argon flow was studied between composite

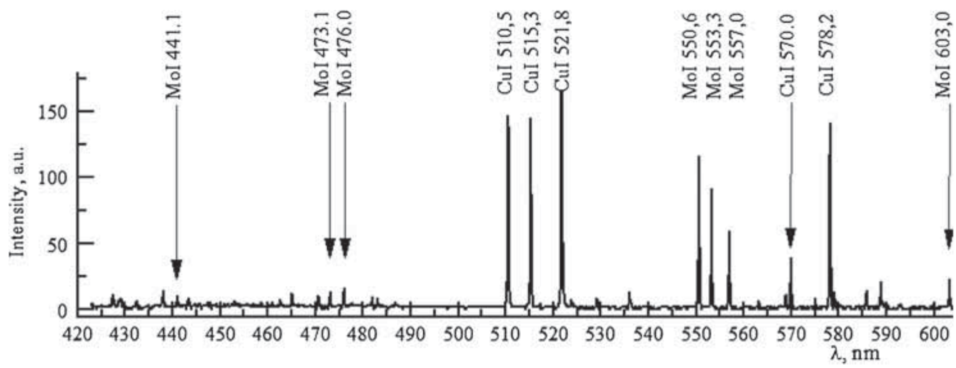

Figure 1. Emission spectrum of plasma of electric arc discharge between composite Cu–Mo electrodes in argon flow at 3.5 A.

Cu–Mo electrodes produced by technology of electron-beam vaporization with further vacuum condensation (see Grechanyuk 2007). Content of molybdenum in the electrodes composition varies from layer to layer and ranges from 1% to 20% with an average value of 12%.

Experimentally obtained emission spectrum of plasma between Cu–Mo electrodes is shown in Figure 1. From this spectrum analysis (see Veklich *et al.* 2013a, b), Mo I spectral lines were preliminarily selected for diagnostics: 441.1, 473.1, 476.0, 550.6, 553.3, 557.0 and 603.0 nm.

It was shown (see Babich *et al.* 2012) that spectral lines Cu I 427.5 and 465.1 nm are overlapped by Mo I 427.6 and 465.2 nm (see Figure 2). Since these lines cannot be applied for diagnostics of plasma containing Cu and Mo, they were withdrawn from this study.

Spectroscopic data of molybdenum atomic lines are shown in Table 2, so one can see a substantial difference between the presented values.

Radiative transition probability A_{ik}, oscillator strength f_{ki}, product of statistical weight of energy level by oscillator strength $g_k f_{ki}$ or common logarithm of this

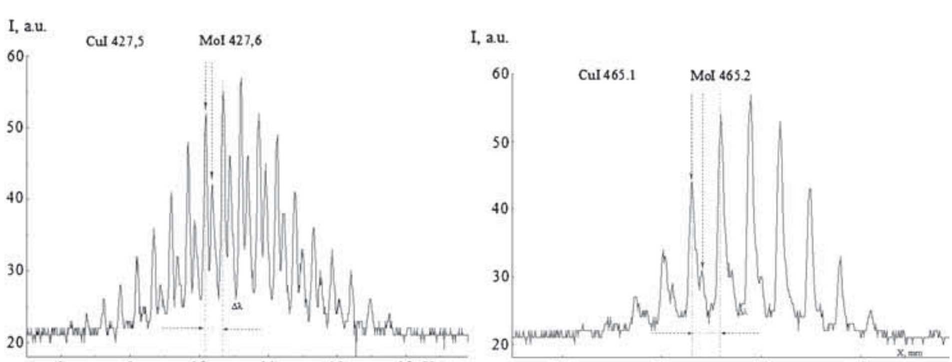

Figure 2. Mutual overlapping of Cu I and Mo I spectral lines.

product $\lg(g_k f_{ki})$ are given in these sources. In order to simplify the analysis, all spectroscopic data were calculated into products of oscillator strengths by statistical weights.

In monography by Corliss & Bozman (1962), spectroscopic data of many elements are listed, which were obtained from experimental investigations of atmospheric plasma of electric arc discharge. In case of Mo I spectral lines, these spectroscopic data are significantly different from those presented in later works, which can be explained by possible deviation of plasma source from LTE and inaccurately calculated plasma temperature (Whaling *et al*. 1984).

Ralchenko *et al.* (2010) and Kurucz & Bell (1995) presented modern electronic databases, which contain data of original investigations. One can see from Table 2 that the data coincide with the results obtained by Whaling & Brault (1988), with slight variations due to conversion and rounding of values.

Schnehage *et al.* (1983) listed values of oscillator strengths for Mo I spectral lines obtained by investigation of plasma emission spectrum of wall-stabilized arc with hollow cathode. For calculation of oscillator strengths, a combination of hook method with emission spectroscopy was applied; expected error of obtained data is 10–30%.

Whaling *et al.* (1984, 1986) and Whaling & Brault (1988) carried out this work with the application of laser-induced fluorescence method. Dye laser allowed to selectively excite separate energy levels and determine lifetime from damping of induced luminescence. Distinction between these works is in application of different plasma sources: plasma of low pressure discharges with hollow cathode (Whaling *et al.* 1984, 1986) and inductively-coupled plasma of subatmospheric pressure (Whaling & Brault 1988). Table 2 shows that the data of Whaling *et al.* (1984) and Whaling & Brault (1988) coincide with 5% error, and data from the work of Whaling *et al.* (1986) differ by the value not more than 10%.

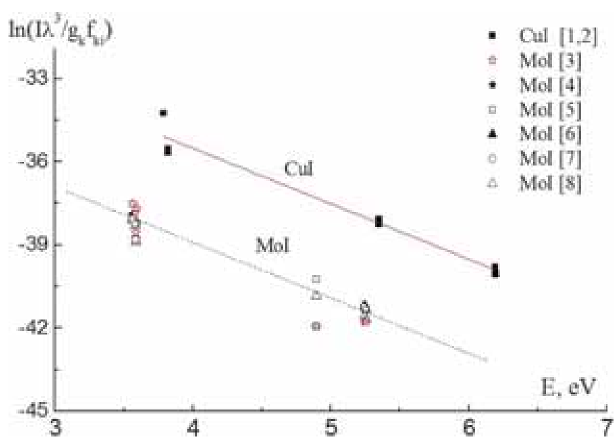

Figure 3. Boltzmann plot involving Cu I and Mo I spectral lines and selection of spectroscopic data for the axial point of the middle cross-section of plasma of free burning electric arc discharge between Cu–Mo electrodes at 3.5 A in argon flow. [1] Boretskij (2011), [2] Babich *et al*. (2010), [3] Corliss & Bozman (1962), [4] Schnehage *et al*. (1983), [5] Whaling *et al.* (1984), [6] Whaling *et al.* (1986), [7] Whaling & Brault (1988), [8] Palmeri & Wyart (1998).

Table 5. List of recommended spectral lines of Mo I, excitation energies and corresponding products of oscillator strengths by statistical weights (Veklich *et al.* 2013b).

λ (nm)	g_k	g_i	E_k (eV)	E_i (eV)	$g_k f_{ki}$	Reference
441.169	11	11	2.08	4.89	1.512	Palmeri & Wyart (1998)
473.144	9	11	2.62	5.24	1.551	Whaling *et al.* (1986)
476.016	11	13	2.65	5.25	2.031	Whaling *et al.* (1986)
550.649	5	7	1.34	3.59	1.149	Whaling & Brault (1988)
553.303	5	5	1.34	3.58	0.854	Whaling & Brault (1988)
557.044	5	3	1.34	3.56	0.460	Whaling & Brault (1988)
603.066	9	7	1.53	3.59	0.359	Whaling *et al.* (1984)

Palmeri & Wyart (1998) have calculated transition probabilities from energy levels using self-consistent Hartree-Fock method. It is to be noted that theoretical values of transition probabilities, as a rule, are higher than experimentally obtained data (see Whaling & Brault 1988), which can be explained by not taking into account polarization effects in atom.

Figure 3 shows Boltzmann plot for Cu I (see Table 1) and Mo I (see Table 2) spectral lines. A solid line is drawn through points, which correspond to Cu I spectral lines, and dashed line through points corresponding to Mo I spectral lines.

Selected values of oscillator strengths for Mo I spectral lines, which provide the best match of slopes in Boltzmann plot are presented in Table 5.

In order to validate selected spectroscopic data, plasma of electric arc discharge between composite copper–molybdenum electrodes in argon flow was studied, and the radial profile of plasma temperature (see Figure 4) was obtained by using the Boltzmann plot method (Figures 5 and 6).

Figures 5 and 6 illustrate that slope of lines for Cu I and Mo I in Boltzmann plots matches in different spatial points for 3.5 and 30 A, which additionally indicates the validity of LTE assumption in plasma.

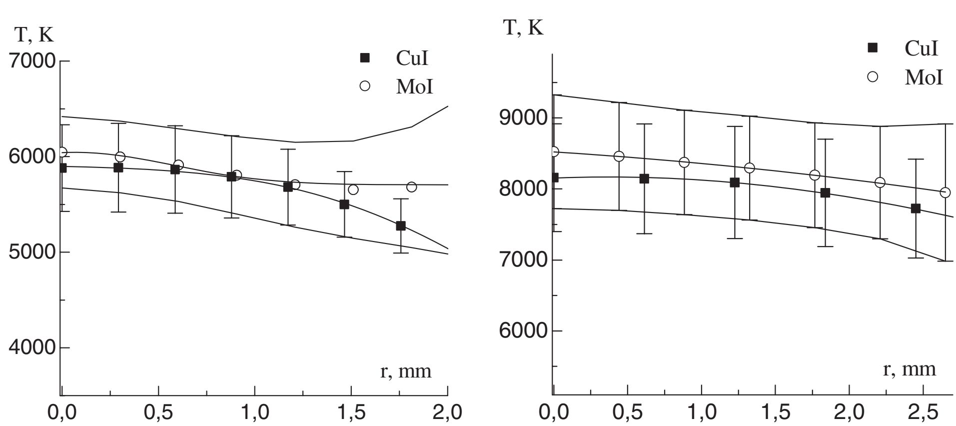

Figure 4. Radial distribution of the plasma temperature of electric arc discharge between Cu–Mo electrodes at 3.5 A (*left*) and 30 A (*right*) in argon flow.

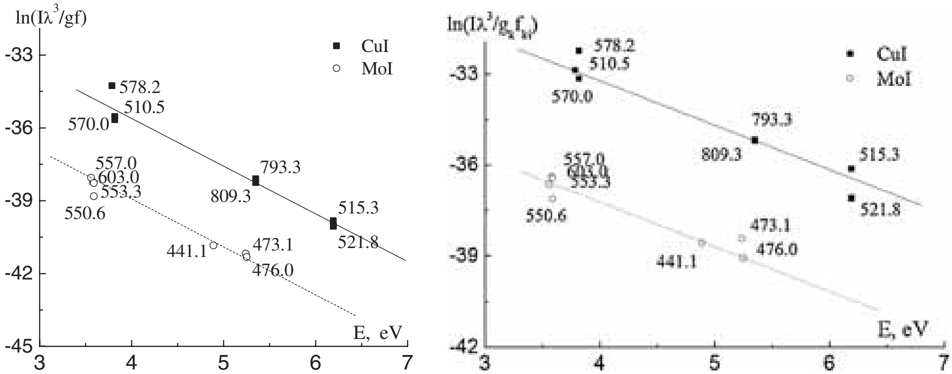

Figure 5. Boltzmann plots of the middle cross-section of plasma of free burning electric arc discharge between Cu–Mo electrodes for the axial point (left) and at a distance of r = 1.2 mm (right) at 3.5 A in argon flow.

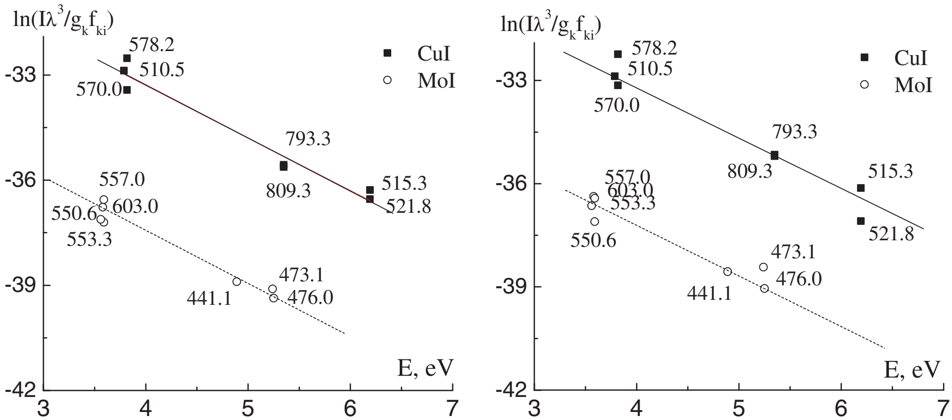

Figure 6. Boltzmann plots involving selected spectroscopic data of molybdenum spectral lines of the middle cross-section of plasma of free burning electric arc discharge between Cu–Mo electrodes for the axial point (left) and at a distance of r = 1.2 mm (right) at 30 A in argon flow.

2.2 *Spectroscopic data of WI atomic lines*

On the basis of analysis of plasma spectrum (Veklich *et al.* 2013a) of electric arc discharge between composite Cu–W electrodes (see Fig. 7), the following W I spectral lines were preliminarily selected for diagnostics: 429.4, 430.2, 468.0, 475.7, 484.3, 488.6, 498.2, 500.6, 501.5, 505.3, 522.4 and 551.4 nm. These lines are listed in Table 3 with corresponding spectroscopic data.

For spectral data selection, plasma of electric arc discharge of 3.5 A current in argon flow between composite Cu–W electrodes (Cu : W = 50 : 50%) was studied.

Data of Ralchenko *et al.* (2010) are in good agreement with values of oscillator strengths obtained by Obbarius & Kock (1982), and data of Kurucz & Bell

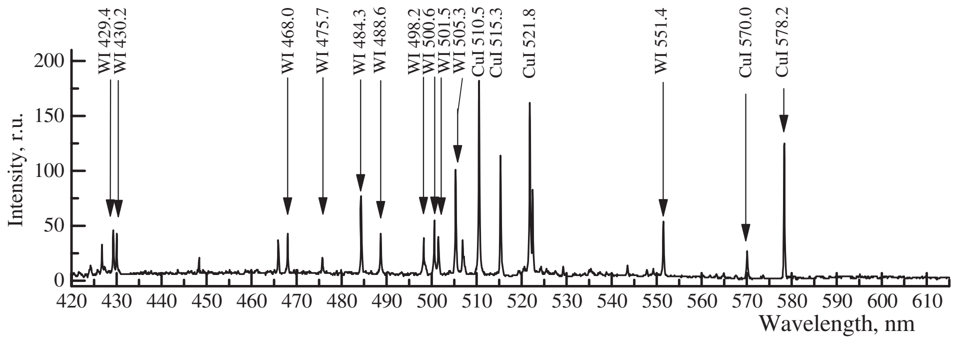

Figure 7. Emission spectrum of plasma of electric arc discharge between composite Cu–W electrodes in argon flow at 3.5 A.

(1995) are in good agreement with values of oscillator strengths obtained by Den Hartog *et al.* (1987).

Absolute values of radiative transitions probabilities of W I atom were calculated by Kirsanova (1969) using optical emission spectroscopy. Plasma of electric arc discharge contained impurities of tungsten, chrome, copper and potassium. Absolute values of transition probabilities of W I lines were obtained by comparison of their intensities with Cr I lines in the assumption that exact absolute values of transition probability for two Cr I spectral lines are known. Ratio of Cr I and W I concentrations was calculated from rates of electrode components erosion into plasma. Temperature was obtained from Cu I spectral lines. It was considered that the presence of potassium would lead to a decrease of spatial gradients of plasma parameters in its volume.

Boltzmann plots for Cu I and W I spectral lines are shown in Figure 8. One can see that spectroscopic data listed in Kirsanova (1969) are in good agreement with linear approximation, but temperature, which was calculated using these values of oscillator strengths, will be significantly lower than that obtained using Cu I lines.

This can be explained by the fact that plasma temperature ($T = 4300 \pm 150$ K) obtained by Kirsanova (1969) is lower than typical temperature under similar experimental conditions (5500–9000 K depending on metal content). Thus, there is a systematic error in calculation of absolute values of transition probabilities of W I lines in this work.

One can see that lines W I 429.46, 430.21 and 475.75 significantly deviate from linear approximation independently of used literature sources, so these lines were withdrawn from consideration. It should be noted that values of oscillator strengths for these W I lines from Obbarius & Kock (1982), Den Hartog *et al.* (1987) and Kling & Kock (1999) are close, so, probably, the problem of diagnostics lies in peculiarities of registration of these lines by spectral devices used in the experiment.

In the work of Obbarius & Kock (1982), oscillator strengths of W I spectral lines are listed, which were obtained by investigations of wall-stabilized arc in argon flow at atmospheric pressure. For excitation of W I lines, tungsten hexafluoride, WF_6, was admixed into plasma. For calculation of oscillator strengths, combination of hook method with emission spectroscopy was applied; expected error of measurements is 10–36%.

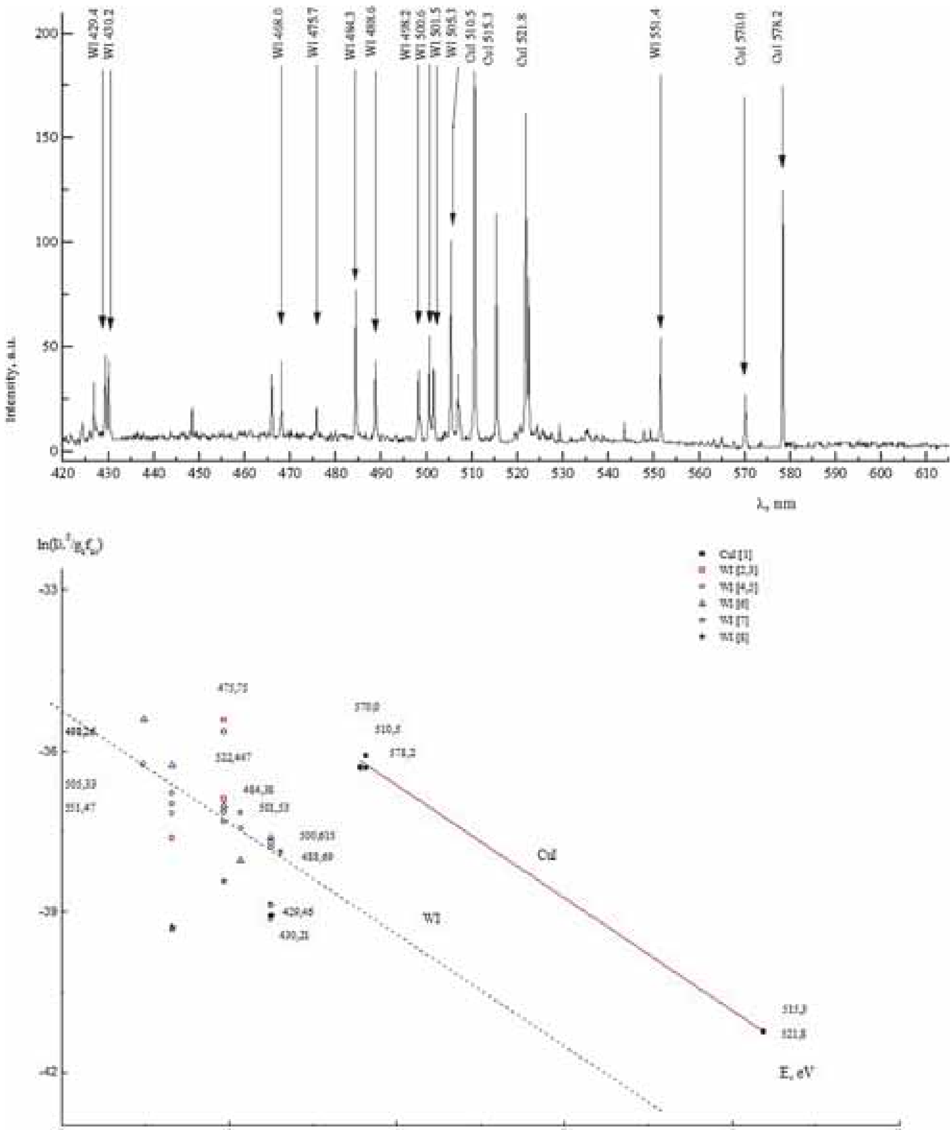

Figure 8. Boltzmann plots and selection of spectroscopic data of tungsten spectral lines in the middle cross-section of plasma of free burning electric arc discharge between Cu–W electrodes for the axial point (*left*) and at a distance of $r = 0.9$ mm (*right*) at 3.5 A in argon flow. [1] Boretskij (2011), [2] Ralchenko *et al.* (2010), [3] Obbarius & Kock (1982), [4] Kurucz & Bell (1995), [5] Den Hartog *et al.* (1987), [6] Kirsanova (1969), [7] Kling & Kock (1999), [8] Thevenin (1989).

In the work of Den Hartog *et al.* (1987), results of determination of absolute values of transition probabilities of W I lines are presented. Peculiarity of this work is the combination of Furrier-spectrometer (which allows to obtain branching ratios – specific fraction of transfer between energy levels) with laser-induced fluorescence method (which allows to selectively excite separate energy levels and determine lifetime from damping of induced luminescence). These techniques were applied to atomic beam injected into low pressure chamber to avoid errors that influence the collisions in plasma.

The best match in slopes of copper and tungsten lines in Boltzmann plots (see Figure 8) in different spatial points is achieved using the spectroscopic data from Den Hartog *et al.* (1987).

A slight deviation from linear approximation in the neighborhood of W I lines 522.46 and 551.4 nm can be explained by large number of spectral lines and intensive continuum emission, which may lead to increased registered intensity in comparison with real intensity of spectral line. However, since the location of points corresponding to W I spectral lines 468.05, 484.38, 488.69, 498.26, 500.615, 501.531, 505.33 nm is in good agreement with the slope obtained from the copper lines, these lines can be applied for diagnostics of plasma with the addition of tungsten (Table 6).

Oscillator strengths by Thevenin (1989), which were obtained by comparing registered and calculated spectra of the Sun emission, are substantially different from other data and do not provide linear approximation in Boltzmann plot. Thus, they were withdrawn from consideration.

Performed selection of copper and tungsten spectral lines allowed to calculate plasma temperature of electric arc discharge between composite Cu–W electrodes (see Figure 9).

Radial profiles of plasma temperature (Figure 10) obtained from copper and tungsten spectral lines coincide within appropriate accuracy.

2.3 *Spectroscopic data of Cr I atomic lines*

Plasma of electric arc discharge of 3.5 A current between Cu–Cr–W electrodes (see Veklich *et al.* 2013c, 2014) was studied to perform the selection of Cr I spectral lines and corresponding spectroscopic data. Electrodes were produced from metal powders with mass ratio of components Cu : Cr : W – 49 : 49 : 2. This technology involves mixing of powders by pressing of samples and sintering them at a temperature of 1200°C in a shielding medium for 1 hour.

Registered emission spectrum is shown in Figure 11. It contains 35 Cr I lines and 5 intensive lines of Cu I. Spectral lines of W I are practically absent in the spectrum,

Table 6. List of recommended spectral lines of W I, excitation energies and corresponding products of oscillator strengths by statistical weights.

λ (nm)	g_k	g_i	E_k (eV)	E_i (eV)	$g_k f_{ki}$	Reference
468.05	7	7	0.60	3.25	0.032	Den Hartog *et al.* 1987
484.38	5	5	0.41	2.97	0.034	
488.69	4	5	0.77	3.31	0.032	
498.26	1	3	0.00	2.49	0.005	
500.615	9	7	0.77	3.25	0.031	
501.531	7	9	0.60	3.07	0.018	
505.33	3	3	0.21	2.66	0.022	
522.466	7	5	0.60	2.97	0.025	
551.47	5	3	0.41	2.66	0.010	

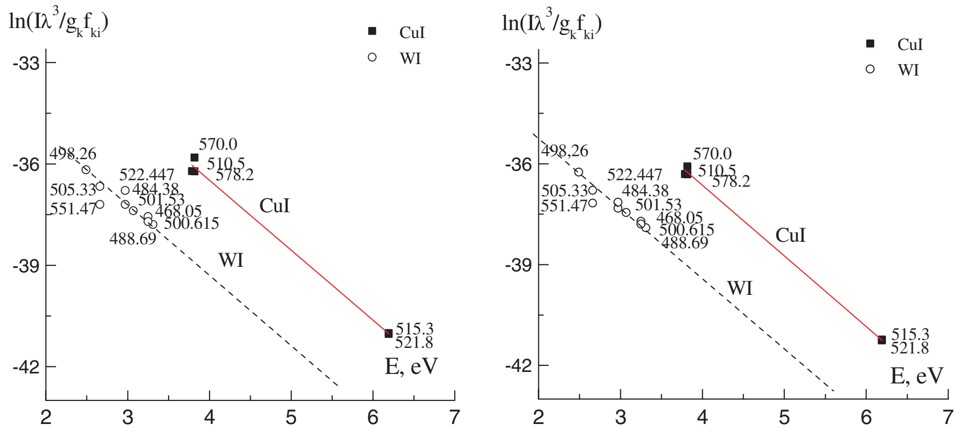

Figure 9. Boltzmann plots involving selected spectroscopic data of tungsten spectral lines of the middle cross-section of plasma of free burning electric arc discharge between Cu–W electrodes for the axial point (*left*) and at a distance of $r = 0.9$ mm (*right*) at 3.5 A in argon flow.

except the weak line W I 522.4 nm due to the low content of this metal in electrode composition. Additional studies of spectral lines' profiles have shown that in case of such electrodes, lines Cu I 427.5 and 465.1 nm are overlapped by neighboring chrome lines, and a large number of Cr I lines overlapped with each other, was observed (see Figure 12). Thus, these lines were withdrawn from consideration.

As a result of spectrum analysis, Cr I lines 435.18, 458.01, 464.62, 487.08, 532.83 and 540.98 nm were selected for plasma diagnostics, which are not overlapped and

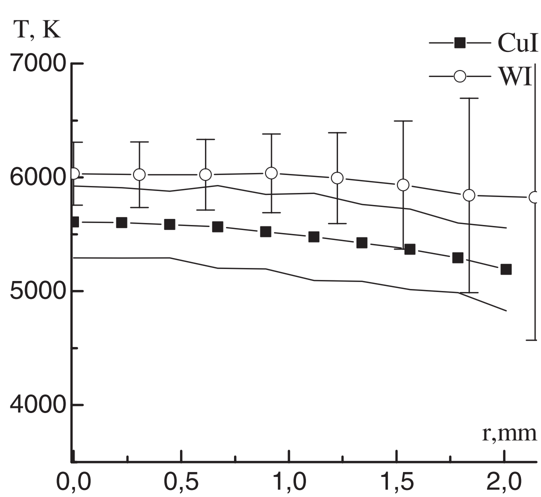

Figure 10. Radial distribution of the plasma temperature of electric arc discharge between Cu–W electrodes at 3.5 A in argon flow.

are intensive enough to be experimentally registered. Spectroscopic data for given lines obtained from database (Ralchenko *et al.* 2010; Kurucz & Bell 1995) and from original works of Younger *et al.* (1978), Sobeck *et al.* (2007) and Wujec (1981) are presented in Table 4.

Ralchenko *et al.* (2010) presented data corresponding to previous works of authors (see Younger *et al.* 1978), and hence the values of oscillator strengths of Cr I 458,006 and 532.834 nm coincided. Younger *et al.* (1978), in turn, presented the compilation of several original works.

The values of radiative transition probabilities of Cr I were presented in Sobeck *et al.* (2007). They used the results of previous works on calculation of lifetimes of energy levels by laser-induced fluorescence method. Branching ratios were obtained by processing of Fourier-spectra of low-pressure lamps emission.

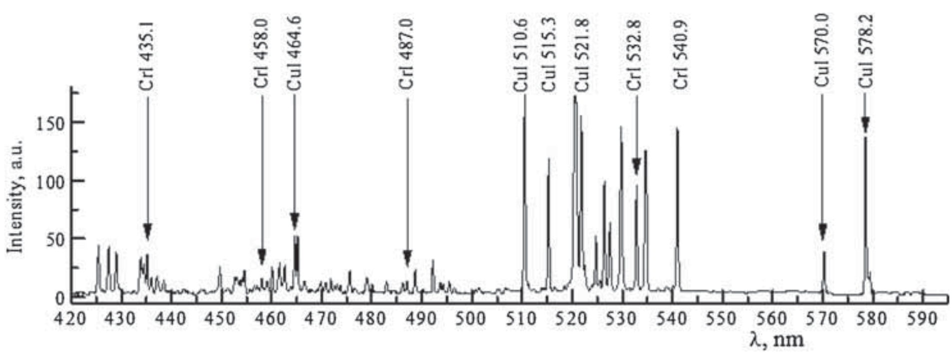

Figure 11. Emission spectrum of plasma of electric arc discharge between composite Cu–Cr–W electrodes in argon flow at 3.5 A.

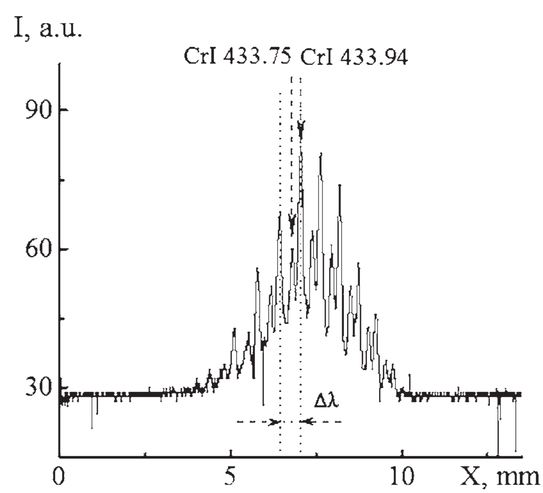

Figure 12. Mutual overlapping of Cr I spectral lines.

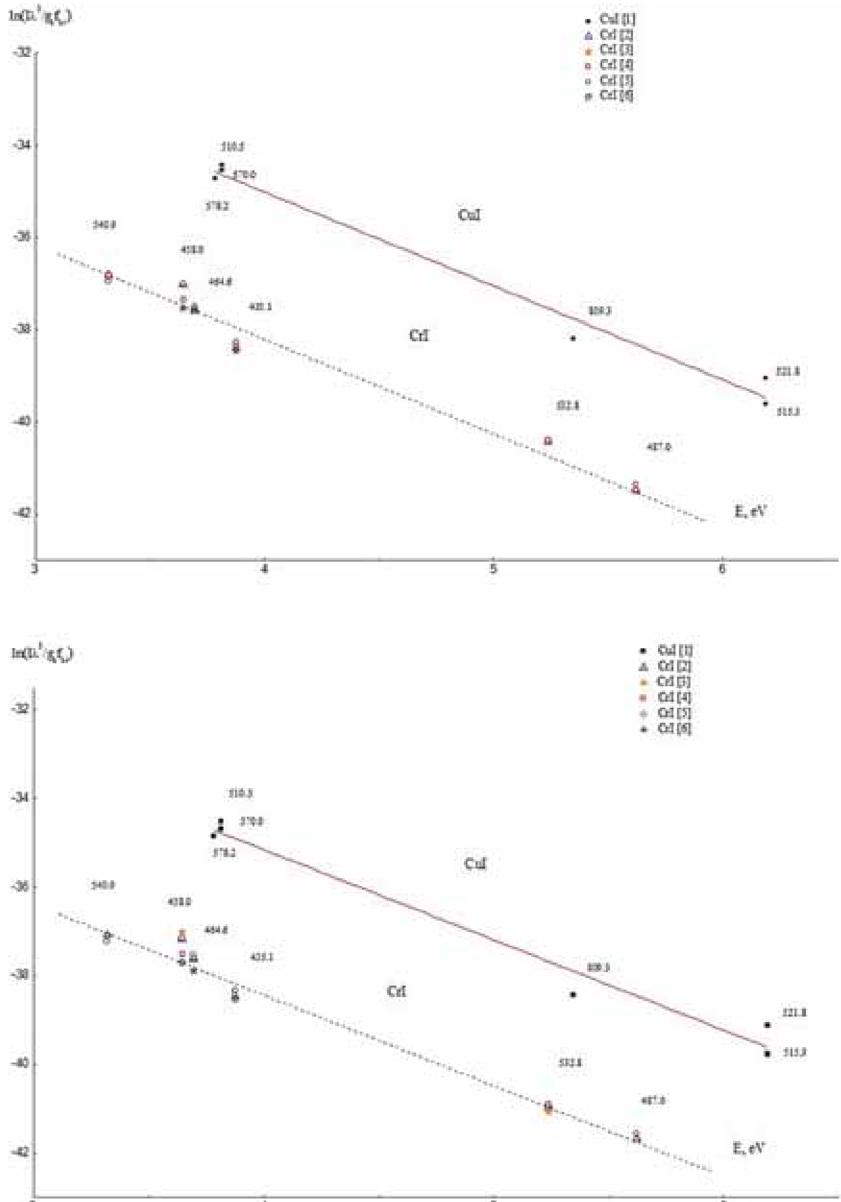

Figure 13. Boltzmann plots involving Cu I and Cr I spectral lines and selection of spectroscopic data of chrome spectral lines for the axial point (*left*) and at a distance of $r = 1$ m (*right*) of the middle cross-section of plasma of free burning electric arc discharge between Cu–Cr–W electrodes at current of 3.5 A in argon flow. [1] Boretskij (2011), [2] Ralchenko *et al.* (2010), [3] Kurucz & Bell (1995), [4] Younger *et al.* (1978), [5] Sobeck *et al.* (2007), [6] Wujec (1981).

The probabilities of radiative transitions were calculated by optical emission spectroscopy in Wujec (1981). Emission of wall-stabilized plasma with addition of chromyl chloride was studied. Since the exact values of accurately calculated

Table 7. List of recommended spectral lines of Cr I, excitation energies and corresponding products of oscillator strengths by statistical weights.

λ (nm)	g_k	g_i	E_k (eV)	E_i (eV)	$g_k f_{ki}$	Reference
435.177	9	11	1.03	3.88	0.331	Sobeck *et al.* (2007)
458.006	5	3	0.94	3.65	0.038	Wujec (1981)
464.617	9	7	1.03	3.70	0.193	Wujec (1981)
487.080	7	9	3.08	5.62	1.12	Ralchenko *et al.* (2010), Kurucz & Bell (1995), Younger *et al.* (1978)
532.834	9	11	2.91	5.24	2.88	Ralchenko *et al.* (2010), Kurucz & Bell (1995), Younger *et al.* (1978)
540.979	9	7	1.03	3.32	0.189	Ralchenko *et al.* (2010), Kurucz & Bell (1995), Younger *et al.* (1978)

probabilities of several Cr I lines were known, the values of transition probabilities by comparison of spectral lines intensities were obtained.

From Figure 13, one can see that the analysis of Boltzmann plots allows to carry out the selection of values of oscillator strengths for Cr I spectral lines from Table 4. It should be noted that data for spectral lines Cr I 487.080, 532.834, 540.979 nm presented in these sources vary insignificantly, so references to these three works are listed in Table 7.

Boltzmann plots (see Figure 14) for midsection plasma of electric arc discharge between composite electrodes show a good agreement between slopes of lines obtained from Cu I and Cr I lines for different spatial points, which allowed to calculate radial profiles of plasma temperature (Figure 15).

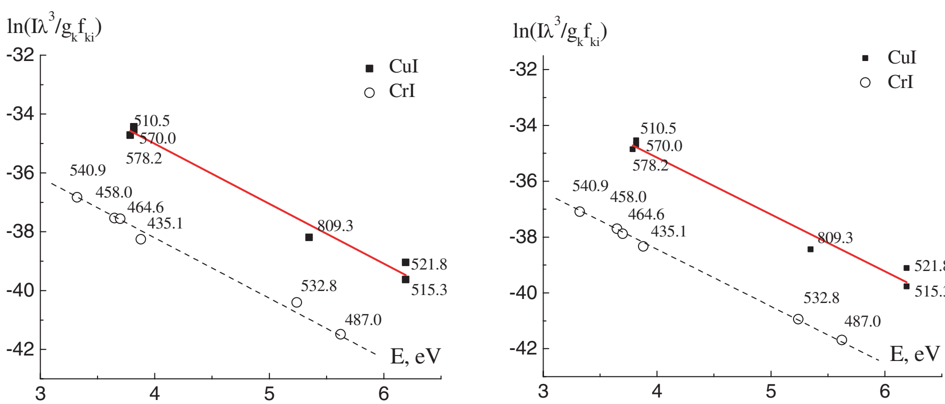

Figure 14. Boltzmann plots involving selected spectroscopic data of chrome spectral lines for the middle cross-section of plasma of free burning electric arc discharge between Cu–Cr–W electrodes for the axial point (*left*) and at a distance of $r = 1$ mm (*right*) at 3.5 A in argon flow.

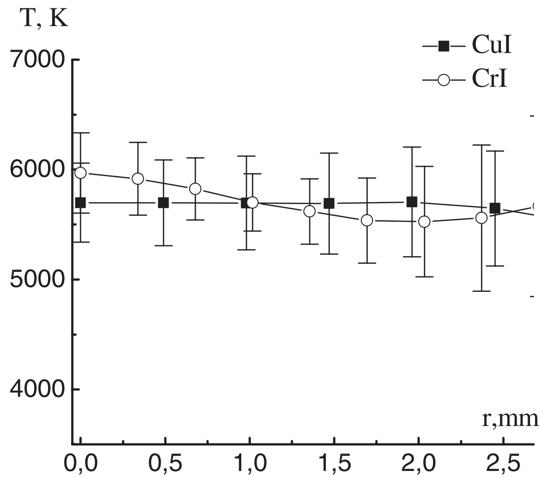

Figure 15. Radial distribution of the plasma temperature of electric arc discharge between Cu–Cr–W electrodes at 3.5 A in argon flow.

3. Conclusions

In this paper, analysis of spectroscopic data from various literature sources of W I, Mo I and Cr I spectral lines was performed. Fundamentals of spectroscopic diagnostics of plasma of electric arc discharge with addition of tungsten, molybdenum and chrome are developed. On the basis of emission spectra analysis and population of energy levels of metals in Boltzmann plots, W I, Mo I and Cr I spectral lines and corresponding values of spectroscopic data, which are appropriate for the purposes of such plasma diagnostics were chosen. Radial profiles of plasma temperature for mid-sections of electric arc discharges in argon flow between composite Cu–W, Cu–Mo and Cu–Cr–W electrodes are obtained.

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